INSTRUMENTATION AND PROCEDURES FOR TRANSIENT MAGNETIC FLUX DENSITY MEASUREMENTS ON AN AIRCRAFT FUSELAGE-LIKE TEST SETUP

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Abstract: The susceptibility of airborne vehicles to electromagnetic (EM) transients has been studied for many years. In the case of a surge current, it flows along the surface of the conducting fuselage and disperses around the circumference. A portion of the surge current also penetrates through the fuselage of the aircraft (by diffusion) resulting in transient EM fields inside the fuselage that can result in EM interference with on-board electronics. In a high current laboratory, an aluminum test cylinder, representative in size and construction of an aircraft fuselage, was subjected to high surge currents, up to 15 kA. The paper discusses measurement system development issues, and the use of fiber optic systems for transient data acquisition.

I. INTRODUCTION

An aircraft might be exposed to surge currents from lightning strokes during thunderstorms. This phenomenon sometimes can be an unavoidable event. The presence of an aircraft in the vicinity of a charged cloud disturbs the equipotential lines between charge centers. The equipotential lines are compressed at the surface of the aircraft and this change produces a higher electric field strength. Since an aircraft can be considered as a metal structure, it can be represented by an equipotential contour (surface).

The aircraft may move closer to a charged cloud and form a path of low resistance, which would eventually cause electric breakdown and subsequent lightning attachment to the metallic airplane structure. Lightning stroke currents may cause direct effects on the airplane and indirect effects on airborne equipment.

The field build-up inside the aircraft affects the EM compatibility performance of the fuselage and sensitive equipment located in it [1, 2, 3].

Understanding the EM field build-up inside an aircraft fuselage test setup due to surge currents is important. Knowing the magnetic flux density (B) distribution inside when the surge current flows through the fuselage can be helpful in evaluating the EM compatibility performance of the airborne equipment in an aircraft.

The main objective of this paper is to describe the instrumentation and procedures developed for transient magnetic flux density measurements on an aircraft fuselage-like test setup.

II. TEST FACILITIES

The High Power Laboratory is a part of the Air Force Research Laboratory (AFRL) at the Wright Patterson Air Force Base (WPAFB). It has a surge current generator (up to 20 kA discharge currents), an aluminum test cylinder simulating an aircraft fuselage, return conductor system, a shielded room, dB/dt probes, current probes, and a data acquisition system utilizing fiber optics for data transmission. The overall test setup shown in Figure 1 includes an 80 kilojoule surge generator.

The aluminum test cylinder simulates the basic geometry of a typical aircraft fuselage. It is manufactured of 0.125 in thick 6061-T4 aluminum sheets. Both ends are closed. The cylinder is 0.965 m (38 in) in diameter, 9.754 m (32 ft) long, and it consists of four sections. For the simulation of aircraft access panels, sixteen panels, 0.61 m by 0.38 m (24 in by 15 in), are available along the cylinder.

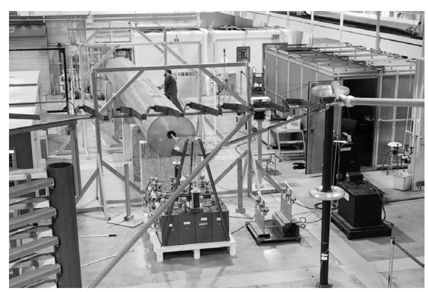

Figure 1. The test setup at WPAFB.

III. dB/dt PROBES

The dual coil probes were designed, fabricated, and tested for the measurement of any magnetic flux density inside and outside the test cylinder that has axial (i.e., along the cylinder), tangential (i.e., circumferential) or radial components. Each dB/dt probe has two orthogonal coils. They are in slots of a small (28 mm) cube, and they can measure any two dB/dt components simultaneously. The synthane body of the dual coil probe and a full probe with coils and terminals are

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14. ABSTRACT
The susceptibility of airborne vehicles to electromagnetic (EM) transients has been studied for many years. In the case of a surge current, it flows along the surface of the conducting fuselage and disperses around the circumference. A portion of the surge current also penetrates through the fuselage of the aircraft (by diffusion) resulting in transient EM fields inside the fuselage that can result in EM interference with onboard electronics. In a high current laboratory, an aluminum test cylinder, representative in size and construction of an aircraft fuselage, was subjected to high surge currents, up to 15 kA. The paper discusses measurement system development issues, and the use of fiber optic systems for transient data acquisition.

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shown in Figure 2. Design of the dual-coil probe is shown in Figure 3.

Each coil consists of 17 turns of 22 AWG enamel coated magnet wire. Electric field shields are placed on both the inner and outer surfaces of each coil. Each shield has a gap located directly opposite the BNC terminal fitting of that coil. The use of dual coil probes is essential for the measurements of current distribution around apertures (windows), or at areas where the current flow is not axial.

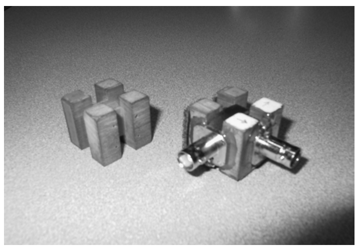

Figure 2. Synthane body without coils and full probe.

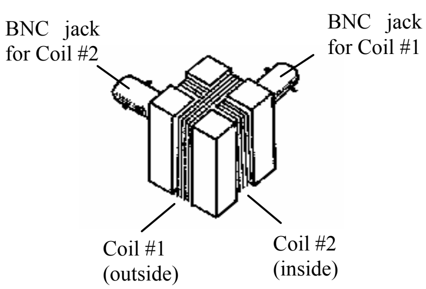

Figure 3. Design of the dual-coil probes.

Since the probe output is proportional to the time derivative of the magnetic flux density produced by the current, the largest output value at the probe coil occurs when the time derivative of the current is the largest. Also, at the time of the peak value of the current, the probe output is zero.

IV. PERFORMANCE TESTS ON PROBES

Several measurements were performed on each dual-coil probe to test their performance. These tests can be divided into four groups.

A. Coil Impedance Measurements

Measurements were performed with an HP 3577A network analyzer and an HP 35676-66301 signal divider in the 5 kHz - 1 MHz frequency range. Figure 4 illustrates the resistance and inductive reactance change of the inner coil of a dB/dt probe.

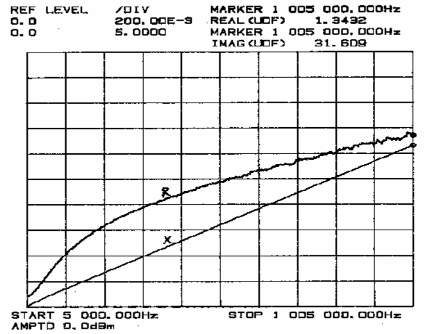

Figure 4. Resistance (upper trace, at 0.2 ohm/div.) and inductive reactance (lower trace, at 5 ohms/div.) change of the inner coil of a dB/dt probe with frequency.

B. Calibration Factor Development for dB/dt Probe Coils

A large air-core solenoid was used for the development of the calibration factor. Its length is 0.61 m, its diameter is 0.32 m, the number of turns is 27. A B/I ratio was expressed based on the solenoid data shown above. It is 492.56 mG/A. The HP 3577A network analyzer was used for the calibration of each probe coil in the large solenoid at swept frequencies, in the 5 kHz - 1 MHz range. The calibration factor measured is the open circuit probe voltage per mG. It is a complex number, its magnitude and phase angle vs. frequency were measured in each case (Figure 5).

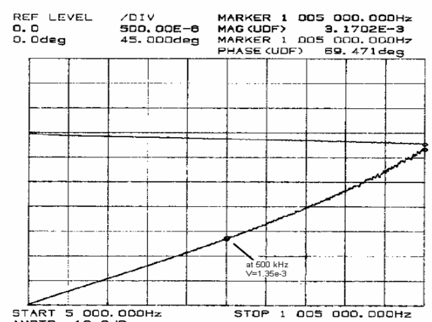

Figure 5. Open circuit voltage magnitude (lower trace, at 500 μV/div.) and phase angle (upper trace, at 45 deg./div.) change of the outer coil with frequency.

C. Exposure to Transient Electric Field

During this test, one of the dual coil probes was exposed to a transient electric field of about 6 kV/cm peak magnitude, using the surge generator of the OSU High Voltage Laboratory, and an appropriate electrode arrangement. The role of this test was to check the performance of the shield of the probe. The shield, well designed and well constructed, reduced the voltage induced in the probe coil (the "pick-up") significantly to the point at which it could be negligible Regular singly shielded cables, doubly shielded cables, and semi-rigid

shielded cables were used for the system tests, in order to see their shielding effects.

D. Effects of Probe Coils on Each Other

Both coils were exposed to transient magnetic fields. The output of the first coil was not influenced by the loading of the second coil with a 50 ohm resistance.

V. FIBER OPTIC SYSTEM TESTS

The fiber optic data acquisition system is a NanoFast OP300-2A system. The components of the system are sensitive. The fiber optic system has a system gain of 10. Since the input limit is $\pm$100 mV, the output is then $\pm$1 V. At that level, the signal-to-noise ratio is 40 dB, or 100:1. Therefore, the noise level at 1 V full output of the fiber optic system is 10 mV.

If the signal level is much lower, then the 10 mV noise level is too high. This was realized when the fiber optic system was used at low signal levels. When the input signal was a clear sinusoidal signal, the output voltage had a signal component and a very significant noise component, far from being a clear sinusoidal signal. Therefore, filtering was necessary.

The first tests were related to the signal amplitudes, waveform retention, and noise levels of the entire (transmitter-cable-receiver) fiber optic system. Another test on all fiber optic systems was related to their gain and frequency dependency. As an example, Figure 6 shows the voltage gain amplitude (G) and phase angle (γ) vs. frequency functions of one of the systems for the frequency range needed. The linear phase shift corresponds to a fixed time delay.

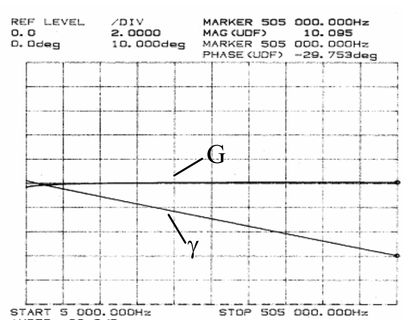

Figure 6. NanoFast OP 300-2A fiber optic system gain amplitude (G, upper trace, at 2 V/div.) and phase angle (γ, lower trace, at 10 deg./div.) vs. frequency functions.

VI. SMALL COMPONENT TESTS

All small component performance characteristics were checked with the HP 3577A network analyzer in the 5 kHz - 1 MHz frequency range. These were the following:

- Connecting cables and BNC fittings and adapters
- 6 dB, 10 dB, 20 dB attenuators for complex attenuation factor
- 1 MHz, 5 MHz, 10 MHz filters for complex transmission coefficient.

VII. TEST SYSTEM RESPONSE

To determine the electrical performance of the dB/dt probes, they were exposed to the magnetic field created by surge currents by using the OSU surge voltage generator. During the experiments both coils of each one of the three dB/dt probes were monitored and their induced voltage outputs were transferred to a scope to evaluate the measurement results. The output of the surge generator was connected to a voltage divider. The divider's voltage ratio was 15,000/1. The low voltage arm of the voltage divider was connected to ground.

One-by-one the inner and outer coils of all cube probes were exposed to the magnetic field of the surge currents flowing in the grounding lead of the voltage divider. During these tests the surge generator output was adjusted to 250 kV and the low voltage arm of the voltage divider (1 ohm) was connected to ground by means of a braided conductor. When the output voltage of the surge generator was 250 kV, at the 1 Ω arm of the voltage divider 250,000/15,000 = 16.66 V was obtained.

During the measurements, the coil of the dB/dt probe to be tested was placed next to the grounding lead of the voltage divider and then the surge generator was discharged. One channel of the scope was used for monitoring the voltage divider output, and the other one for the probe output voltage.

For the monitoring of the low voltage arm voltage of the voltage divider, 42dB attenuation (i.e., an attenuation factor of 126) was used to protect the fiber optic system and the scope. Satisfying the requirement that the fiber optic receiver load must be 50 ohms, a 50 ohm resistor was connected across the scope terminals. At 250 kV surge voltage output, the expected voltage on the scope was 662 mV. The voltage measured was 648 mV, a satisfactory accuracy.

Since the measured traces were noisy, a 1 MHz low pass filter was used at the scope to get cleaner wave shapes. The upper trace of Figure 7 shows a typical surge voltage; it corresponds to the surge current flowing in the grounding lead. The lower trace is the dB/dt probe output, proportional to the derivative of the surge current shown as the upper trace. In this figure one time division corresponds to 5 μs. The maximum value of the voltage seen at the scope is about 600 mV for this measurement. Due to the fact that the voltage divider is resistive, the current and voltage wave shapes are practically identical.

Since the dB/dt probe output is proportional to the derivative of the magnetic flux density produced by the current, the largest output value of the probe coil occurs when the current change is the fastest. Also, at the time of the peak value of the current, the dB/dt probe output is zero. The dB/dt probe output, which is shown as the lower trace of Figure 7, has a very good wave shape satisfying the expectations.

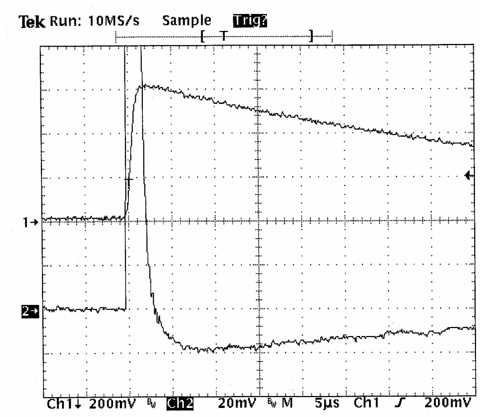

Figure 7. Typical surge current (upper trace) and dB/dt probe output (lower trace).

As the last step, the performance of the entire interconnected instrumentation system (i.e., the probe, fiber optic transmitter, fiber optic cable, fiber optic receiver, scope, attenuators, filters, cables, BNC fittings), was determined.

Figure 8 shows a sample record of system tests at OSU. The upper trace shows a transient current of about 16.5 A peak value at about 2.5 µs zero-to-maximum time. This was a relatively small current through the voltage divider of the surge voltage generator. The output of the divider was attenuated, and one of the fiber optic systems was used for signal transmission. The lower trace shows the output of one of the dual coil probes, through filters and another one of the fiber optic systems. The probe was placed next to the ground return lead of the voltage divider.

Waveforms of the fiber optic system input and system output were practically identical, and almost noise-free at their level of optimal magnitude.

VIII. CONCLUSIONS

Dual coil probes were designed, fabricated, and tested for the measurement of any magnetic flux density inside or outside the test cylinder that has axial (i.e., along the test cylinder) or tangential (i.e., circumferential) or radial components.

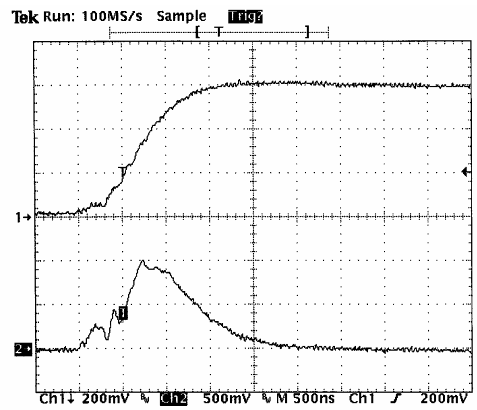

Figure 8. Response of the entire system measured at OSU, upper trace -- transient current, lower trace -- dB/dt probe coil output.

Response of the entire measurement system was measured and the results show that dual coil dB/dt probes are successful for the measurement of transient magnetic fields.

IX. ACKNOWLEDGMENTS

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